

Use of inter-channel correlated observation errors in GSI

Ricardo Todling
with
Wei Gu and Dacian N. Daescu*

Global Modeling and Assimilation Office, NASA

* Portland State University, Portland, Oregon

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Outline

- 1 Introduction & Motivation
- 2 Estimates from GEOS: IASI & AIRS
- 3 Studying Potential Benefit from Correlated R
- 4 Preliminary Results: Fully correlated IASI R
- 5 Closing Remarks



Remarks on Residual Statistics

Observation-minus-Background (OmB) residuals

$$\mathbf{d}_o^b = \mathbf{y}^o - \mathbf{H}\mathbf{x}^b$$

OmB error covariance matrix

$$\langle \mathbf{d}_o^b (\mathbf{d}_o^b)^T \rangle = \mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R}$$

- Sample error covariances of OMB residuals have traditionally been used to estimate and model time-independent background error covariances (Schlatter 1974, Hollingsworth & Lönnberg 1986, Dee & da Silva 1999, Franke 1999, and others, going back to the work of T. Kailath in the 70s).
- The expression above holds independently of optimality (though it relies on assumptions about background and observation errors).



Remarks on Residual Statistics: Sequential Approach

Other available residuals:

$$\mathbf{d}_o^a = \mathbf{y}^o - \mathbf{H}\mathbf{x}^a$$

$$\mathbf{d}_b^a = \mathbf{H}\mathbf{x}^b - \mathbf{H}\mathbf{x}^a$$

which lead to the following cross-covariances:

$$\langle \mathbf{d}_o^a (\mathbf{d}_o^b)^T \rangle = \mathbf{R} + o(\Delta\mathbf{K})$$

$$\langle \mathbf{d}_b^a (\mathbf{d}_o^b)^T \rangle = \mathbf{H}\mathbf{B}\mathbf{H}^T + o(\Delta\mathbf{K})$$

$$\langle \mathbf{d}_b^a (\mathbf{d}_o^a)^T \rangle = \mathbf{H}\mathbf{A}\mathbf{H}^T + o(\Delta\mathbf{K})$$

where $\Delta\mathbf{K}$ is the deviation of the sequential filter gain from optimality.

REMARK: Only under the assumption of optimality, $\Delta\mathbf{K} = \mathbf{0}$, the cross-covariances become covariances and the expressions above can be used to estimate observation, background, and analysis error without concerns (Desroziers et al. 2005).



Remarks on Residual Statistics: Variational Approach

FGAT 3dVar, for example, solves:

$$J(\delta\mathbf{x}, \beta) = J_b + J_o + J_x$$

with

$$J_b(\delta\mathbf{x}, \beta) = \frac{1}{2} \delta\mathbf{x}^T \mathbf{B}^{-1} \delta\mathbf{x} + \frac{1}{2} (\beta^b - \beta)^T \mathbf{B}_\beta^{-1} (\beta^b - \beta)$$

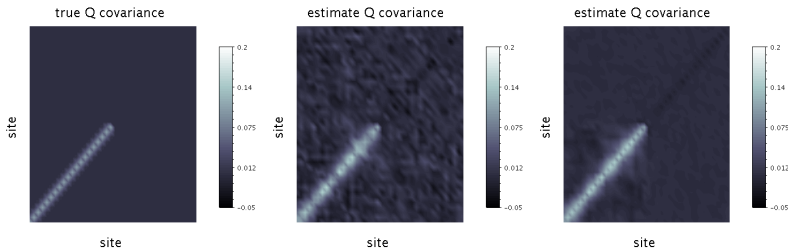
$$J_o(\delta\mathbf{x}, \beta) = \frac{1}{2} \sum_{k=1}^K [\mathbf{H}_k \delta\mathbf{x} - \mathbf{d}_k + \sum_n \beta_n \bullet \mathbf{p}_n]^T \mathbf{R}_k^{-1} [\mathbf{H}_k \delta\mathbf{x} - \mathbf{d}_k + \sum_n \beta_n \bullet \mathbf{p}_n]$$

where residuals are collected over a whole time window (similar for 4dvar).

REMARK: Derivation of residual cross-covariances corresponding to those of the sequential approach must be inferred carefully to try minimizing, if not possibly avoiding altogether, introducing time correlations.



***REMARK:** The validity of replacing the expectation operator, $\langle \bullet \rangle$, with the typical time average operator might not always be justifiable.*

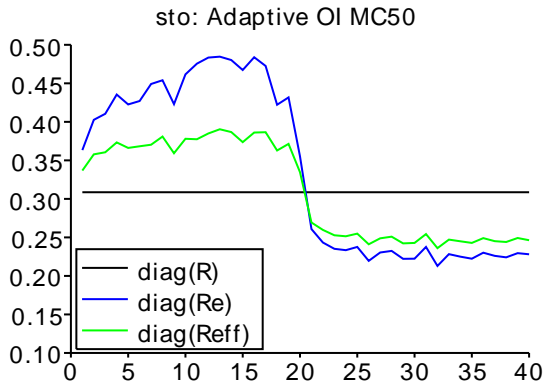


From Todling and Trémolet (2009; unpublished)

It might be possible to address this concern in practice by making use of residuals now available from ensemble hybrid procedures to data assimilation.



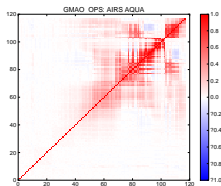
REMARK: Blaming the observations for what ends up being model error might have odd implications.



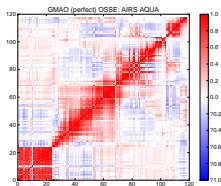
From Todling (2015; QJRM)



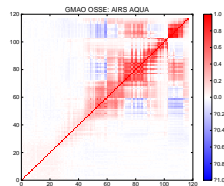
REMARK: Until an OSSE is well tuned, it might show rather spurious "observation error"



From GEOS-5 OPS



From early OSSE (perfect obs)



From tuned OSSE

OSSE results from exps in Errico et al. (2013; QJRM5)
 Results here from Todling (2015; QJRM5)



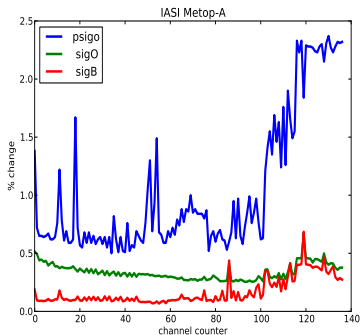
Estimation procedure from GEOS residuals

- Sample residuals from December 2013
- Examples from IR instruments: AIRS & IASI (& briefly CrIS)
- Only clear-sky radiances are currently used in GSI
- Land residuals are not considered
- Only take residuals within 30 min around synoptic time
- Only complete profiles are taken in estimation
- Estimation done using *Desroziers* diagnostic (forced symmetrization)

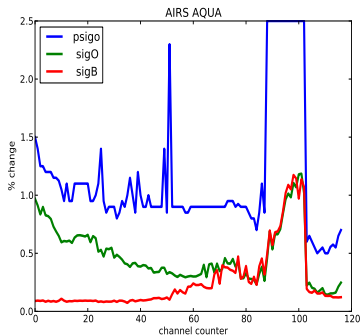


Standard Deviations: Prescribed and Estimated

IASI 137 Channels

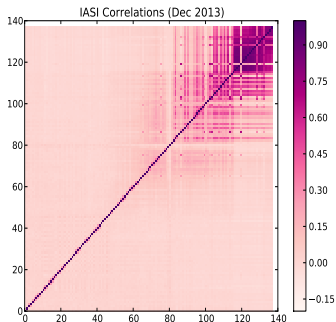


AIRS 117 Channels



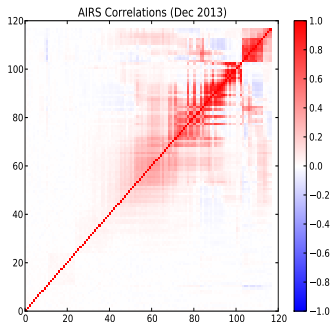
Estimated Observation Correlations

IASI 137 Channels



Left: similar to Fig. 12 in Bormann et al. (2010)

AIRS 117 Channels

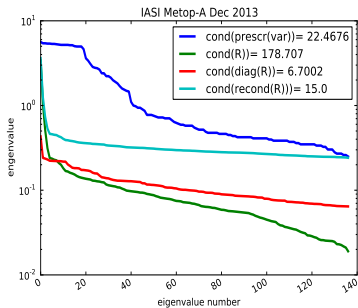


Right: similar to Fig. 9 in Bormann et al. (2010)

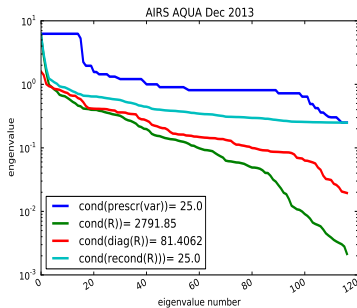


Spectra of Estimated Error Covariances

IASI 137 Channels



AIRS 117 Channels

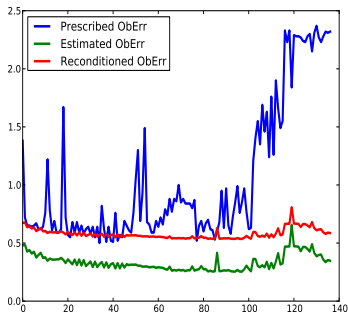


Left: similar to Fig. 8 in Weston et al. (2014)

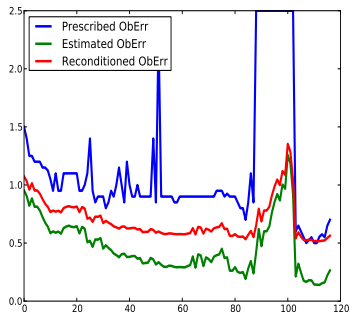


Standard Deviations

IASI 137 Channels



AIRS 117 Channels

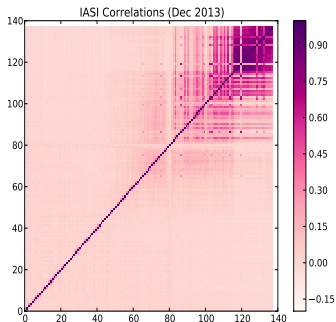


Left: similar to Fig. 9 in Weston et al. (2014)



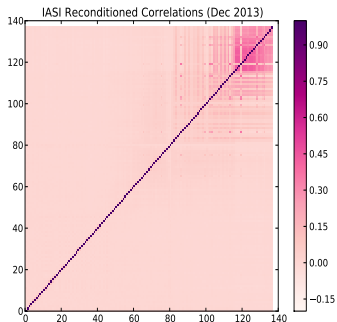
Estimated Observation Correlations

IASI raw R



Left: similar to Fig. 2 in Weston et al. (2014)

IASI reconditioned R

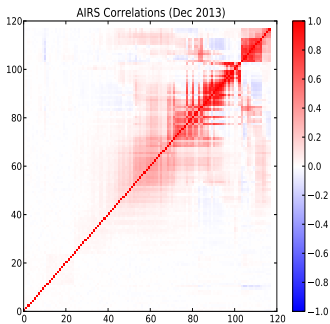


Right: similar to Fig. 10 in Weston et al. (2014)

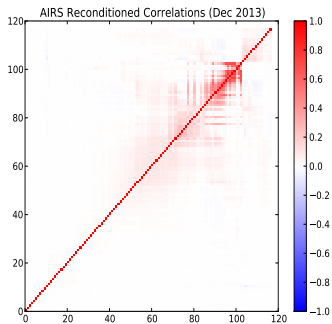


Reconditioned Observation Correlations

AIRS raw R

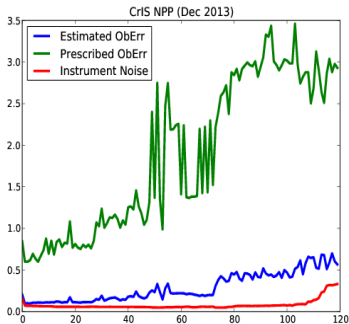


AIRS reconditioned R

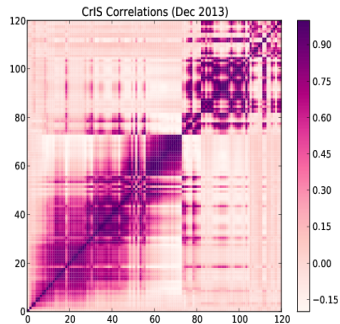


Just a previous: CrIS on NPP

Standard Deviations



Correlations



Experimental Setting:

- GEOS ADAS: GEOS AGCM + 3dVar GSI + IAU
- Time period: December 2013
- Test (low) resolution: $1^\circ \times 1.25^\circ \times 72$
- Evaluations calculate sensitivity of 24-hour forecast to changes in **R**

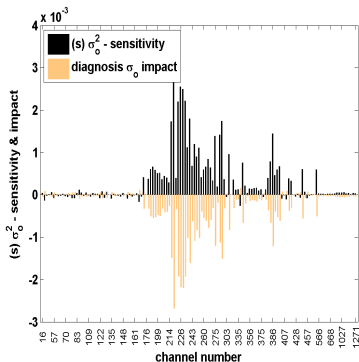


Sensitivities to observation error: $\frac{\partial e}{\partial \sigma_i^o} = - \langle (\mathbf{d}_o^a)_i, \frac{\partial e}{\partial \mathbf{y}_i^o} \rangle$

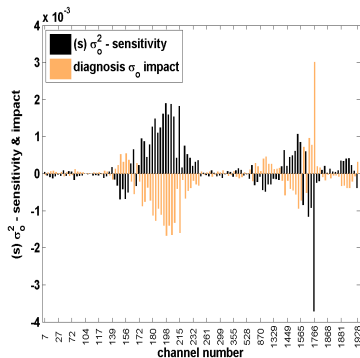
Impact to change in observation error: $\frac{\partial e}{\partial \sigma_i^o} \delta \sigma_i^o$

Sensitivities and Potential Impact on 24-hour Forecast

IASI 137 Channels



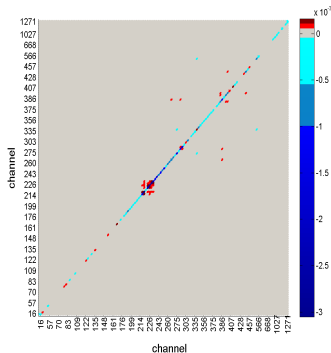
AIRS 117 Channels



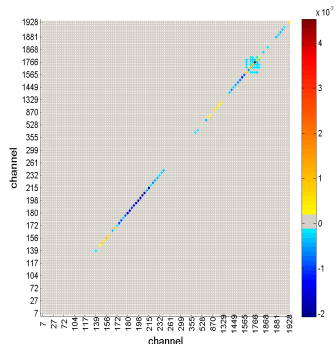
Forecast error impact assessment: $e(\tilde{R}) - e(R) \approx < \frac{\partial e}{\partial R}, (\tilde{R} - R) >$

Potential Impact on 24-hour Forecast

IASI 137 Channels



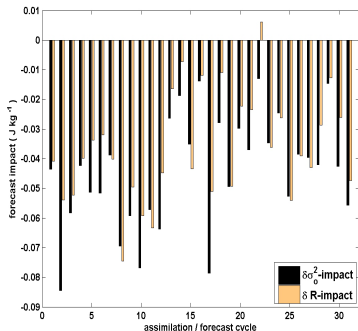
AIRS 117 Channels



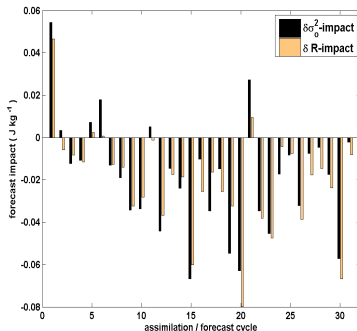
Forecast error impact assessment: $e(\tilde{\mathbf{R}}) - e(\mathbf{R}) \approx \text{trace}(\langle \frac{\partial e}{\partial \mathbf{R}}, (\tilde{\mathbf{R}} - \mathbf{R}) \rangle)$, for each channel for all cycles over Dec 2013.

Potential Impact on 24-hour Forecast

IASI 137 Channels



AIRS 117 Channels

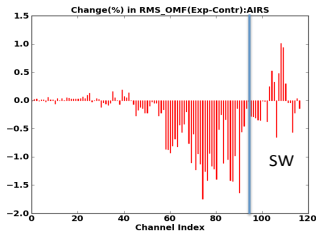


Experimental Setting:

- GEOS ADAS: GEOS AGCM + 3dVar GSI + IAU
- Time period: June 2014
- Test (low) resolution: $1^\circ \times 1.25^\circ \times 72$
- Fully correlated MetOp-A IASI observation error covariance
- Reconditioning strategy as in Weston et al. (2014)



Percentage Change AIRS Residual Global RMS



GMAO-GSI, fully corr R (IASI)

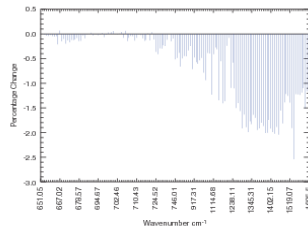
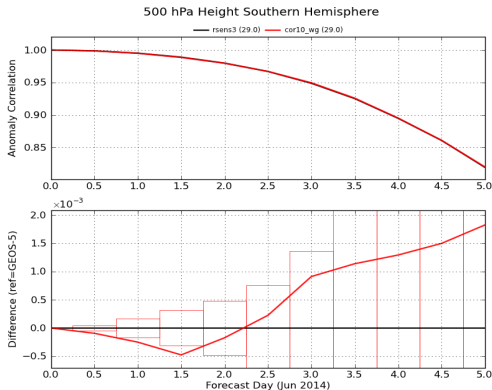


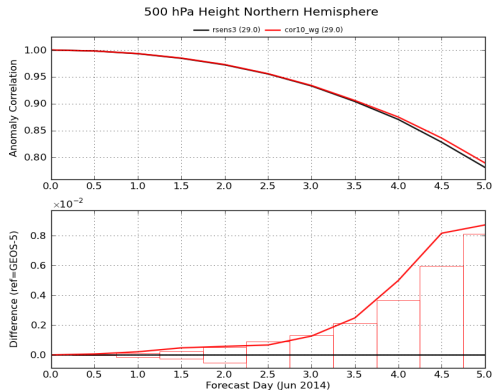
Figure 13. Percentage change in background fit to AIRS observations averaged over the entire winter trial period. This figure is available in colour online at wileyonlinelibrary.com/journal/qj

From Weston et al. (2014)

Forecast Anomaly Correlation: H500 - SH



Forecast Anomaly Correlation: H500 - NH



Closing Remarks

- Observation error covariance for multiple MW and IR instruments have now been estimated for GEOS ADAS (GSI).
- Large condition number for IR error covariance matrix estimates corroborates *Weston et al. (2014)*.
- Capability to account for these errors is now available in GSI.
- Preliminary study of potential benefit of changing **R** indicates changing standard deviations might bring largest contribution.
- Preliminary tests with fully-correlated IASI **R** produce mildly positive improvement in NH skill, with improved use of AIRS.
- Experimentation with other sensors, and a full resolution ADAS, is ongoing.

